43rd Aerospace Mechanism Symposium Abstract

Subject: Design & Development of NEA Scout Solar Sail Deployer Mechanism

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Abstract

The 6U (~10cm x 20cm x 30cm) cubesat Near Earth Asteroid (NEA) Scout, projected for launch in September 2018 aboard the maiden voyage of the Space Launch System (SLS), will utilize a solar sail as its main method of propulsion throughout its ~3 year mission to a near earth asteroid. Due to the extreme volume constraints levied onto the mission, an acutely compact solar sail deployment mechanism has been designed to meet the volume and mass constraints, as well as provide enough propulsive solar sail area and quality in order to achieve mission success. The design of such a compact system required the development of approximately half a dozen prototypes in order to identify unforeseen problems and advance solutions. Though finite element analysis was performed during this process in an attempt to quantify forces present within the mechanism during deployment, both the boom and the sail materials do not lend themselves to achieving high-confidence results. This paper focuses on the obstacles of developing a solar sail deployment mechanism for such an application and the lessons learned from a thorough development process. The lessons presented here will have significant applications beyond the *NEA Scout* mission, such as the development of other deployable boom mechanisms and uses for gossamer-thin films in space.

Executive Summary

The NEA Scout solar sail design comes as a successor to two 3U (~10cm x 10cm x 30cm) cubesats: the NASA Marshall Space Flight Center (MSFC) developed solar sail NanoSail-D and the Planetary Society solar sail Lightsail-A (Lightsail-B to be launched in 2016). Both spacecraft flew technology demonstration missions in Low Earth Orbit (LEO): NanoSail-D in 2010 (Figure 1) and Lightsail-A in 2015 (Figure 2). These two cubesats represent pathfinders on the way to utilizing solar sail propulsion to achieve science missions, such as the primary science objective for NEA Scout: image and characterize a Near Earth Asteroid. NASA has taken an interest in applying cubesat form factors, methodologies, and risk to perform cost effective interplanetary science missions. Solar sail technology is a key to enabling that capability. While it is conceivable for a 6U cubesat mission to reach a NEA with conventional chemical propulsion, both the number of targets and the launch window would be tightly constrained.


Figure 1: NanoSail-D (10m^2 Sail)

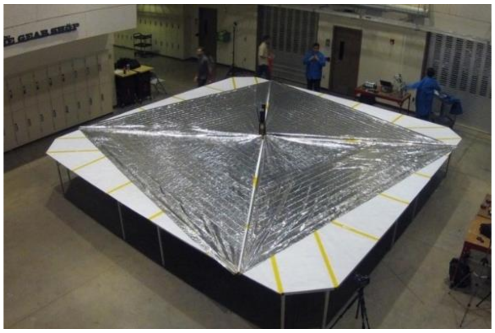
Figure 2: LightSail (32m^2 Sail)

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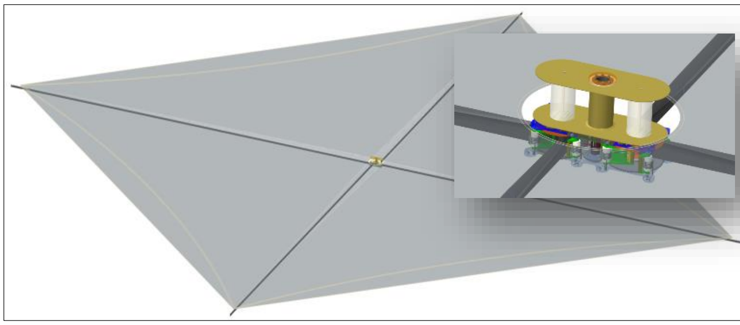


Figure 3 & 4: NEA Scout (86m^2 Sail) & Boom Deployer Prototype for NEA Scout

NanoSail-D, LightSail, and NEA Scout (Figures 1, 2, 3, & 4) all make use of Triangular Rollable and Collapsible (TRAC) booms originally developed by AFRL (Air Force Research Laboratory) and currently produced by NeXolve (Huntsville, AL). As the sail for each mission grew,10m^2, 32m^2, and 86m^2 respectively, the boom length also grew, 2.2m, 4m, and 6.7m respectively. At larger lengths, new complications arose during deployment. For example, due to the strain energy developed while spooling, TRAC booms can slip past one another during deployment, causing the outer diameter in the spool to expand radially. A reaction referred to as 'blooming' and leading to complications. If not controlled properly during deployment, 'blooming' of the boom during deployment can lead to suboptimal deployment and possibly failure (Figure 5).

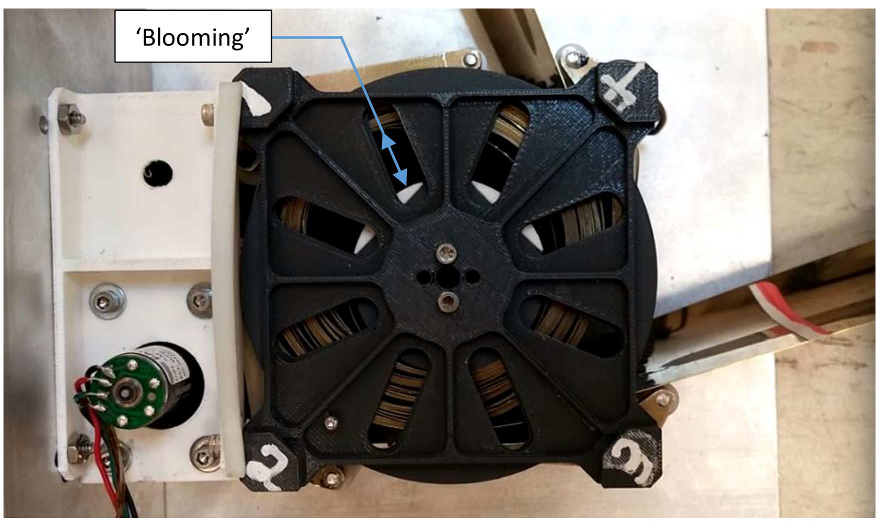

Figure 5: Point of Deployment Where 'Blooming' Causes Failure

Several techniques have been developed in order to either eliminate or mitigate 'blooming' during deployment. These techniques are also applicable to other booms. In fact, during the development of the *NEA Scout* boom deployer, very slight modifications were made to allow for a split tape composite boom (Figures 6, 7, & 8). The split tape composite boom spooled tighter and deployed with greater ease to the metallic TRAC boom. Despite the advantages of a split tape composite boom (including a large weight savings), it was not chosen due to its greater height and thus inability to fit within the allotted volume (6.5cm compared to 3.5cm TRAC boom height).

Figure 6, 7, & 8: Split Tape Composite Boom Deployer (Version 1 & 2)

The solar sail design for NEA Scout similarly produced many design challenges. The original baseline for NEA Scout was a four quadrant sail in order to benefit from the heritage designs of NanoSail-D and Lightsail. However, after examining the thermal environment experienced by the TRAC booms, it became evident that thermal deformation would prove too great for an effective solar sail. Initial results for an unloaded 7.3m TRAC boom at a 30^{o} angle of incidence to the sun indicated 1.48m of tip displacement (Figure 9). This result was at least 1 order of magnitude greater than what would be considered acceptable from a Guidance, Navigation, & Control (GN&C) perspective. This was determined to be caused by the low thermal conductivity along the thin profile of the boom, the self-shading one half of the boom's profile by the sunward half, and the suboptimal optical properties of the uncoated TRAC boom (solar absorptivity and infrared (IR) emissivity).

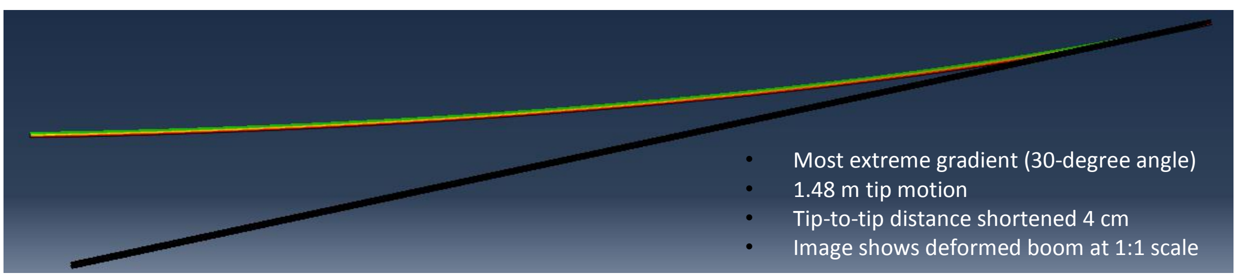

Figure 9: 7.3m Uncoated, Unshaded, Unloaded TRAC Boom

Extensive analysis and testing were performed to determine the best method for mitigating boom thermal deflection, including an aluminum coating for the TRAC boom and the use of a 'sock' to keep the boom from direct sunlight. The final determination was to change the configuration to a single sail design, which would inherently shade that majority of the boom from the root to ~16cm from the tip. An integrated model analysis shows that max out-of-plane boom tip displacement reduced from ~100cm in the four quadrant case to ~4cm in the shaded boom case (Figure 10 & 11). Figure 10 also shows a large amount of in-plane displacement that further convinced designers to move to a single sail. Additionally, the single sail increases the flatness of the sail, reducing the sail connection points from 12 to 4 interfaces.

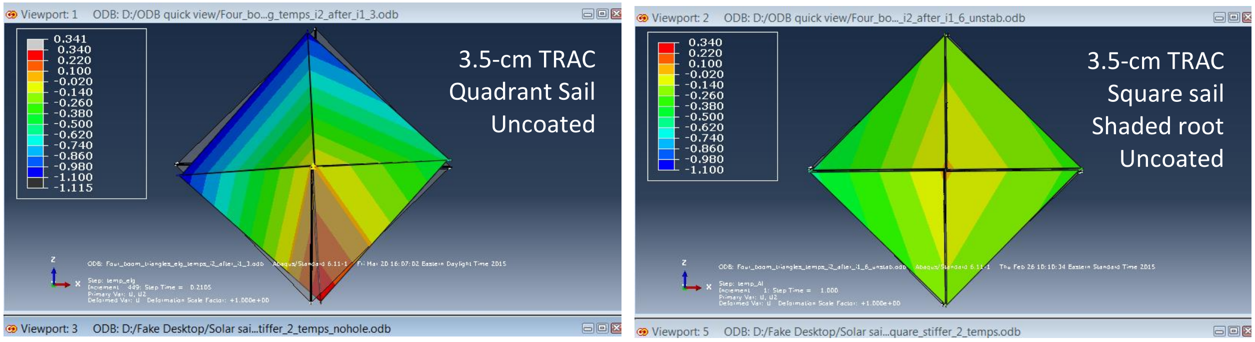

Figure 10 & 11: Thermal Deformation Results for Four Quadrant and Single Quadrant Sail

Designing a deployment scheme for a single sail entailed further complexities for the solar sail deployment mechanism. Due to the placement of the solar sail deployment mechanism in the center of the spacecraft bus, the single square sail is packaged on a single oblong spool (Figure 3). A center post is utilized to connect the two halves of the spacecraft structurally and pass-through a relatively large cable bundle.

In order to optimize the load going into the sail, the connection of the boom tip to the sail corner was improved from a linear tension spring, as used by NanoSail-D and Lightsail, to a constant force spring. The sail membrane is expected to thermally expand by ~2.9cm more than the booms at each corner. In order to account for this, the linear spring would have to be designed reasonably long, with a low spring coefficient, or a large force range would have to be accepted in the sail membrane and boom. By using a constant force spring, the force range should be constrained within a +/-5% range and the size of the spring can be reduced, therefore reducing the total boom length.

The challenges inherent in development of such technology with the unusually rigorous constraints of a 6U cubesat require a thorough development program. The resulting lessons are enlightening to the complexities of a successful solar sail mission. These lessons will prove instrumental in advancing solar sail capability and expanding the use of the technology.